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OPTIMUM DESIGN OF WATER HARVESTING STRUCTURES BY COMPUTER

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Optimum Design of Water Harvesting Structures by Computer¹

Gary W. Frasier²

INTRODUCTION

Most water harvesting catchment and storage structures in the United States are used as supplemental water supplies for livestock and wildlife. Catchment and storage sizes have usually been determined by precedent, irrespective of rainfall, actual water requirements, or relative unit costs of catchment and storage. The standard size structure for livestock usage in the Southwest has generally been a catchment of 950 square meters (10,000 square feet) and a storage reservoir of 75,000 to 150,000 liters (20,000 to 40,000 gal.).

For each water harvesting installation, there are many combinations of catchment and reservoir sizes that will provide an adequate water supply. One combination would be a relatively small catchment area with a large storage reservoir to collect the water during periods of high precipitation and provide ample carryover into

periods of low precipitation. A second combination would be a small reservoir with a large catchment area which would collect sufficient water during the periods of low precipitation. The combination of lowest total cost is determined by the relative unit costs of catchment and storage structures.

Computations necessary for determining the relative sizes of catchment and storage for providing adequate water supplies at the lowest total cost are not difficult, but are tedious and time consuming when all possible combinations of rainfall patterns, water requirements, and unit construction costs are considered. A computer program was written to perform these computations and determine the size combination of catchment and reservoir that could be constructed to provide the required water supply at the lowest total cost.

DESCRIPTION OF PROGRAM

The program, presented in appendix I, is written in Fortran IV language, is approximately 6,000 characters long, and will run on most computers which have a Fortran compiler. The input-output statements may have to be changed to accommodate some computers. All measurement units are in the metric system. Basically, the program computes the costs of a series of catchment area and storage volume combinations that will meet the water requirements. The sizes of catchment area and storage volume for each of these combinations is determined by computing at preset intervals a water balance of (a) the amount of precipitation collected, (b) the quantity of water in storage, and

(c) the quantity of water required. The lowest total cost combination is selected as the optimum structure.

The program consists of a main program, OPTMZ, and three subroutines—CHECK, VARCST, and RESVR. A block flow diagram of the program and subroutines is presented in appendix II. OPTMZ computes the catchment runoff efficiency, performs the incrementing for changing catchment and storage sizes, computes the total costs of catchment and storage, and prints the results.

Subroutine CHECK performs the water balance by time intervals for the given catchment and storage sizes. Subroutine VARCST computes the unit costs of catchment and storage. Subroutine RESVR computes the storage dimensions for open-type storage. An option is available in the program for selecting the type of storage desired. Butyl bags or covered tanks would be representative of closed-type storage. Open-type storage is assumed to be an excavated, open-top reservoir.

¹Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture.

²Research hydraulic engineer, U.S. Water Conservation Laboratory, Phoenix, Ariz.

DATA INPUT

The information supplied to the program is:

1. Number of time intervals—monthly intervals for 1 year would be represented by the number 12; weekly intervals for 1 year would be represented by the number 52.
2. Quantity of water required (use) per interval in liters.
3. Quantity of precipitation by interval in millimeters.
4. Code for selecting open- or closed-type storage—
1 is used for open-type storage
2 is used for closed-type storage.
5. Angle in degrees from horizontal of sideslopes for open-type storage.
6. Desired depth for open-type storage in meters.

7. Minimum storage capacity in liters. To prevent the possibility of continuous looping in the program, the storage capacity should be equal to or larger than the largest water usage requirement for any individual time interval.

8. Coefficients of the polynomial describing the catchment costs in dollars per square meter. This polynomial may be of second order.

9. Coefficients of the polynomial describing the storage costs in dollars per thousand liters. This polynomial may be of second order.

10. Coefficients of the polynomial describing the catchment runoff efficiency. This polynomial may be of third order. Typical input data are presented on page 4.

COMPUTATION PROCEDURE

OPTMZ PROGRAM

The first step of the optimization procedure starts with the computation of the catchment runoff efficiency. The quantity of water collected from a catchment will usually be *less* than 100 percent of the precipitation because of retention, infiltration, or absorption of the catchment surface. The catchment runoff efficiency may be assumed constant if rainfall versus runoff data are not available for more accurate computation. When sufficient data are available, variable runoff efficiency can be better approximated by a general second or third order polynomial equation as follows:

$$y = A + Bx + Cx^2 + Dx^3 \quad (1)$$

where

$$\begin{aligned} y &= \text{catchment runoff efficiency} \\ x &= \text{total precipitation per interval.} \end{aligned}$$

Next, the program computes an initial catchment area based on the sums of precipitation and water use for all time intervals as follows:

Catchment area (m.²)

$$= \frac{\text{total water use (liters)}}{\text{total precipitation (mm.)} \times \text{runoff efficiency}} \quad (2)$$

With this catchment area, a water balance for each time interval is calculated in subroutine CHECK with no limitation on maximum storage size. If the quantity of water required and the quantity collected do *not* balance for all intervals, the catchment area is increased by 10 percent, and the water balance is again computed. This procedure is continued until a water balance for all intervals is obtained. If open-type storage is required, the dimensions of the reservoir are determined in subroutine RESVR. Because an open-top storage collects water directly, the surface area of the reservoir is subtracted from the required catchment area. After determining the unit costs in subroutine VARCST, the total cost of the structure is computed and stored with the required catchment area and maximum storage volume.

The third step consists of reducing the maximum storage volume by a specified amount and computing the catchment area necessary to provide an adequate water supply. The storage volume is reduced by a quantity (x) that is equal to 5 percent of the difference between the maximum storage and the initially assigned minimum allowable storage. The water balance is checked in subroutine CHECK. The catchment area is allowed to increase by 10-percent increments until a water balance is achieved. If open-type storage is required, the dimensions of the reservoir are determined in subroutine RESVR. The total cost of the structure is computed and stored with the required catchment area and maximum storage volume. This procedure is continued for a total of 19 times. Each time the maximum reservoir volume is reduced by the quantity (x).

The fourth step of the optimization procedure is the selection of the previously computed catchment-storage combination of the lowest cost and printing of results. The complete water balance by intervals is printed by subroutine CHECK and includes the following: TOTAL PRECIPITATION, TOTAL USE, MAXIMUM STORAGE, and MINIMUM STORAGE. The main program prints CATCHMENT AREA, COST OF CATCHMENT AND STORAGE, TOTAL COST, COST FUNCTIONS FOR CATCHMENT AND STORAGE, and CATCHMENT EFFICIENCY FUNCTION.

If open-type storage is used, water will be lost by evaporation, which may cause an insufficient water supply during some intervals. The sizes of catchment and storage that allow for evaporative losses are determined first by running the program assuming no evaporation. Then, using the dimensions of storage as computed by the program, the quantity of water lost by evaporation is estimated for each interval and added to the use data. The program is then rerun, and new storage dimensions are computed. This procedure is continued until the change in dimensions is less than 10 percent.

SUBROUTINE CHECK

In subroutine CHECK, the water balance for each time interval is determined. Water collected is computed (catchment area $\times$ precipitation $\times$ runoff efficiency) and added to water carried over in storage from the previous interval. This quantity is compared to the quantity required for the interval in question, plus the succeeding interval. Initially, the storage volume is allowed to change to store any water over the required amount. In the next step, the computations are performed with the maximum storage volume preassigned. With preassigned storage, more water may be collected than can be stored, which results in an overflow. Computations proceed interval by interval as long as the water balance is maintained. Should insufficient water be collected or in storage for the required use, a larger catchment area is assigned by the main program.

SUBROUTINE RESVR

The storage dimensions for open reservoirs computed in subroutine RESVR are based on the shape of an inverted obelisk. The volume of an obelisk is given by equation (3).

$$(V_1) = 1/6 h [ab + (a + a_1)(b + b_1) + a_1 b_1] \quad (3)$$

where

- h = depth of storage in meters
- a = top length of storage in meters

- b = top width of storage in meters
- a_1 = bottom length of storage in meters
- b_1 = bottom width of storage in meters
- V_1 = volume in cubic meters.

By letting the top width be one-half the top length as follows:

$$b = a/2 \quad (4)$$

and expressing the bottom lengths and widths in terms of the top length and the depth as follows:

$$a_1 = a - 2h \cotangent \alpha \quad (5)$$

$$b_1 = a/2 - 2h \cotangent \alpha, \quad (6)$$

where

α = angle in degrees from the horizontal of sides of the storage,

equation (3) can be written and simplified as follows:

$$\begin{aligned} (h/2)a^2 - (3/2h^2 \cotangent^2 \alpha) a \\ + (4/3 h^3 \cotangent^2 \alpha - V_1) = 0. \end{aligned} \quad (7)$$

By letting—

$$x = h/2 \quad (8)$$

$$y = -3/2 h^2 \cotangent^2 \alpha \quad (9)$$

$$z = 4/3 h^3 \cotangent^2 \alpha - V_1, \quad (10)$$

equation (7) can be solved for the top length (a) by the quadratic formula as follows:

$$a = \left\{ -y + [y^2 - 4xz]^{0.5} \right\} / 2x, \quad (11)$$

where the depth (h) is preassigned.

SUBROUTINE VARCST

The unit costs of catchment and storage are computed in subroutine VARCST. These costs may be assumed constant or as a variable dependent upon the size of catchment and storage. Variable unit cost functions can be approximated satisfactorily by the general second order polynomial function, equation (1), where

y = unit cost per area or volume

x = area or volume.

Unit catchment costs are in dollars per square meter. Unit storage costs are in dollars per thousand liters. These cost estimates will probably be different for various locations.

USE OF PROGRAM

The following two examples show the use of the program for designing catchment-storage water harvesting structures.

Example 1

A rancher near Sedona, Ariz., needs sufficient water for 25 cattle for the grazing period of 1 October through 30 May. The rainfall record at nearby Montezuma Castle National Monument is believed to be representative of the area. Each of the cattle requires 38 liters of water per day (10 gal. per day). The rancher decides to use an open-type storage of 1:1 sideslope with a membrane-type lining. Cost estimates for a series of storage sizes are determined and plotted as shown in figure 1. The cost estimate curve is then approximated by a polynomial equation for use in the computer program. The polynomial is given by equation (12).

$$y = 44.3166 - 0.471199x + 0.0016438x^2 \quad (12)$$

where (x) is the storage volume in thousands of liters. A similar procedure is used to determine the unit costs of the catchment and can be approximated by the polynomial—

$$y = 2.330 - 0.0011458x + 0.0000001824x^2 \quad (13)$$

where (x) is the catchment area in square meters. Using the best available data, the efficiency of the catchment area for collecting rainfall is approximated by the polynomial—

$$y = 0.46 + 0.0378x - 0.00117x^2 + 0.0000112x^3 \quad (14)$$

where (x) is the total monthly rainfall in millimeters. Because the precipitation data used are averages, which could vary from year to year, the rancher decided the minimum storage would be 2 months' supply (57,000 liters). There is sufficient soil depth to construct a storage reservoir 2.1 m. (7 ft.) deep. The input data for the program are as follows:

1. Number of intervals—12.
- 2, 3. Water use and precipitation by interval:

<u>Interval</u> <u>(Month)</u>	<u>Precipitation</u> <u>(Millimeters)</u>	<u>Use</u> <u>(Liters)</u>
Jan.	27.2	28,400
Feb.	21.1	28,400
Mar.	22.1	28,400
Apr.	20.1	28,400
May	7.1	28,400
June	7.4	0
July	37.1	0
Aug.	52.6	0
Sept.	31.6	0
Oct.	21.3	28,400
Nov.	16.0	28,400
Dec.	26.9	28,400

4. Code for type of storage—1.
5. Angle of sideslope of storage—45.
6. Depth of storage—2.1.
7. Minimum size storage—57,000.
8. Coefficients of catchment costs—A = 2.330, B = 0.0011458, C = 0.0000001824.
9. Coefficients of storage costs—A = 44.3166, B = -0.471199, C = 0.0016438.
10. Coefficients of runoff efficiency—A = 0.46, B = 0.0378, C = -0.00117, D = 0.0000112.

The results for example 1 are presented in table 1. The catchment area is 2,469 m.², and the maximum storage is 106,830 liters. The reservoir top dimensions are: width, 6.6 m.; length, 13.1 m. The catchment and storage costs are \$1,514 and \$1,360, respectively. These results do not allow for evaporative losses from the reservoir. Using the reservoir dimensions, the evaporation is estimated at approximately 4,000 liters per month during the winter, increasing to 18,000 liters per month in June and July. The results of the second running of the program, in which evaporation is added to water use, are presented in table 2. The new catchment area is 2,847 m.² and has a maximum storage of 100,735 liters. The costs are \$1,556 for catchment and \$1,363 for storage. The storage dimensions changed less than 10 percent; therefore, as previously noted this is the final result.

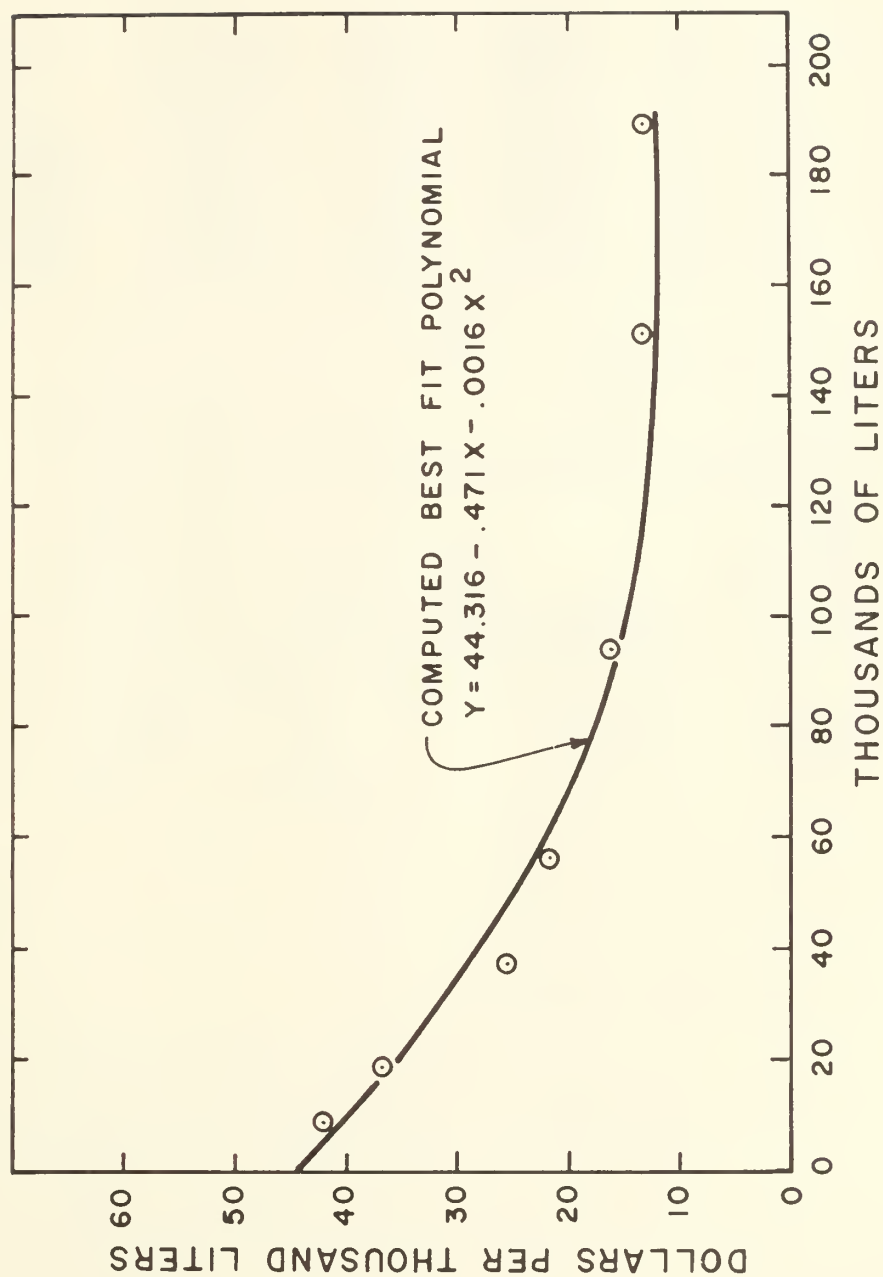


FIGURE 1.-Cost estimates of storage for example 1.

TABLE 1.—Results for example 1 with minimum storage of 57,000 liters

MONTH OR WK	PRECIP (MM)	EFFIC	RUNOFF (LITERS)	USE (LITERS)	STORAGE (LITERS)	OVERFLOW (LITERS)
JAN	27.2	0.85	58929.9	28400.0	30529.9	0.0
FEB	21.1	0.84	45388.6	28400.0	47518.6	0.0
MAR	22.1	0.84	47705.5	28400.0	66824.1	0.0
APR	20.1	0.84	43039.4	28400.0	81463.5	0.0
MAY	7.1	0.67	12216.4	28400.0	65279.9	0.0
JNE	7.4	0.68	12860.8	0.0	78140.7	0.0
JLY	37.1	0.82	78101.2	0.0	106828.4	49413.4
AUG	52.6	0.84	113045.2	0.0	106828.4	113045.2
SPT	31.6	0.84	67788.0	0.0	106828.4	67788.0
OCT	21.3	0.84	45854.7	28400.0	106828.4	17454.7
NOV	16.0	0.81	33161.2	28400.0	106828.4	4761.2
DEC	26.9	0.85	58298.8	28400.0	106828.4	29898.8
	290.5			227200.		

MAXIMUM STORAGE = 106828.4

MINIMUM STORAGE = 30529.9

CATCHMENT AREA = 2468.6 SQ.M.

STORAGE DIMENSIONS IN METERS

WIDTH = 6.6

LENGTH = 13.1

DEPTH = 2.1

COST FUNCTIONS

CATCHMENT $Y = 2.3303 + -.0011 * X + 0.000000 * X^{**2}$ STORAGE $Y = 44.3166 + -.4712 * X + 0.001644 * X^{**2}$

CATCHMENT EFFICIENCY FUNCTION

 $Y = 0.4600 + 0.0378 * X + -.001170 * X^{**2} + 0.00001120 * X^{**3}$

COSTS

CATCHMENT = \$1514.04

STORAGE = \$1360.86

TOTAL = \$2874.90

TABLE 2.—Results for example 1 with increased water use to allow for evaporation losses from storage

MONTH OR WK	PRECIP (MM)	EFFIC	RUNOFF (LITERS)	USE (LITERS)	STORAGE (LITERS)	OVERFLOW (LITERS)
JAN	27.2	0.85	67571.4	32410.0	35161.4	0.0
FEB	21.1	0.84	52044.4	33050.0	54155.7	0.0
MAR	22.1	0.84	54701.0	37520.0	71336.7	0.0
APR	20.1	0.84	49350.7	40430.0	80257.4	0.0
MAY	7.1	0.67	14007.8	44810.0	49455.2	0.0
JNE	7.4	0.68	14746.7	18050.0	46151.9	0.0
JLY	37.1	0.82	89553.9	18050.0	100735.0	16920.8
AUG	52.6	0.84	129622.0	16410.0	100735.0	113212.0
SPT	31.6	0.84	77728.3	12590.0	100735.0	65138.3
OCT	21.3	0.84	52578.8	38060.0	100735.0	14518.8
NOV	16.0	0.81	38023.9	34420.0	100735.0	3603.9
DEC	26.9	0.85	66847.6	32410.0	100735.0	34437.6
	290.5			358210.		

MAXIMUM STORAGE = 100735.0

MINIMUM STORAGE = 35161.4

CATCHMENT AREA = 2847.1 SQ. M.

STORAGE DIMENSIONS IN METERS

WIDTH = 6.4

LENGTH = 12.9

DEPTH = 2.1

COST FUNCTIONS

CATCHMENT $Y = 2.3303 + -.0011 * X + 0.000000 * X^{**2}$

STORAGE $Y = 44.3166 + -.4712 * X + 0.001644 * X^{**2}$

CATCHMENT EFFICIENCY FUNCTION

$Y = 0.4600 + 0.0378 * X + -.001170 * X^{**2} + 0.00001120 * X^{**3}$

COSTS

CATCHMENT = \$1556.30

STORAGE = \$1363.03

TOTAL = \$2919.34

Example 2

A family of four living on the island of Maui in Hawaii needs a permanent water supply for household use. The family uses 750 liters per day (200 gal. per day) and lives in an annual rainfall zone of 2,600 mm. (100 inches). Past records show that precipitation occurs every week. It was estimated that storage of 10,000 to 20,000 liters would be required, and that a butyl bag of this size would cost \$50 per 1,000 liters. The catchment will be a rubber membrane that has a runoff efficiency of approximately 100 percent and costs \$2.50 per square meter, regardless of catchment size. Because rainfall does occur every week, the minimum storage required was set at 6,000 liters (1 weeks' use). The input data for this example are as follows:

1. Number of intervals—52.
- 2, 3. Water use and precipitation by interval—see table 3.
4. Code for type of storage—2.
5. Angle of sideslope of storage—0.
6. Depth of storage—0.
7. Minimum size storage—6,000.
8. Coefficients of catchment costs—A = 2.50, B = 0, C = 0.
9. Coefficients of storage costs—A = 50.0, B = 0, C = 0.
10. Coefficients of runoff efficiency—A = 1.0, B = 0, C = 0, D = 0.

The results for this example are presented in table 3. A maximum storage of 19,200 liters is required with a catchment area of 200 m.² The catchment costs \$510 and the storage costs \$960.

TABLE 3.—Results for example 2

MONTH OR WK	PRECIP (MM)	EFFIC	RUNOFF (LITERS)	USE (LITERS)	STORAGE (LITERS)	OVERFLOW (LITERS)
1	82.7	1.00	16811.1	5200.0	11611.1	0.0
2	18.8	1.00	3821.6	5200.0	10232.7	0.0
3	6.6	1.00	1341.6	5200.0	6374.3	0.0
4	24.1	1.00	4899.0	5200.0	6075.3	0.0
5	30.4	1.00	6179.6	5200.0	7053.9	0.0
6	80.2	1.00	16302.9	5200.0	18155.8	0.0
7	57.6	1.00	11708.8	5200.0	19220.0	5444.6
8	43.4	1.00	8822.3	5200.0	19220.0	3622.3
9	52.1	1.00	10590.8	5200.0	19220.0	5390.8
10	71.2	1.00	14473.4	5200.0	19220.0	9273.4
11	52.3	1.00	10631.4	5200.0	19220.0	5431.4
12	148.0	1.00	30085.1	5200.0	19220.0	24885.1
13	103.8	1.00	21100.2	5200.0	19220.0	15900.2
14	58.7	1.00	11932.4	5200.0	19220.0	6732.4
15	38.2	1.00	7765.2	5200.0	19220.0	2565.2
16	40.1	1.00	8151.4	5200.0	19220.0	2951.4
17	65.8	1.00	13375.7	5200.0	19220.0	8175.7
18	3.4	1.00	691.1	5200.0	14711.1	0.0
19	30.0	1.00	6098.3	5200.0	15609.5	0.0
20	23.1	1.00	4695.7	5200.0	15105.2	0.0
21	83.1	1.00	16892.4	5200.0	19220.0	7577.6
22	2.3	1.00	467.5	5200.0	14487.5	0.0
23	26.9	1.00	5468.2	5200.0	14755.7	0.0
24	18.1	1.00	3679.3	5200.0	13235.0	0.0
25	20.7	1.00	4207.8	5200.0	12242.9	0.0
26	53.8	1.00	10936.3	5200.0	17979.2	0.0
27	46.8	1.00	9513.4	5200.0	19220.0	3072.6
28	43.8	1.00	8903.6	5200.0	19220.0	3703.6
29	76.8	1.00	15611.7	5200.0	19220.0	10411.7
30	38.4	1.00	7805.9	5200.0	19220.0	2605.9
31	45.4	1.00	9228.8	5200.0	19220.0	4028.8
32	115.7	1.00	23519.2	5200.0	19220.0	18319.2
33	43.5	1.00	8842.6	5200.0	19220.0	3642.6
34	40.9	1.00	8314.1	5200.0	19220.0	3114.1
35	37.2	1.00	7561.9	5200.0	19220.0	2361.9
36	29.5	1.00	5996.7	5200.0	19220.0	796.7
37	28.7	1.00	5834.1	5200.0	19220.0	634.1
38	37.3	1.00	7582.3	5200.0	19220.0	2382.3
39	18.5	1.00	3760.6	5200.0	17780.6	0.0
40	22.8	1.00	4634.7	5200.0	17215.4	0.0
41	65.5	1.00	13314.7	5200.0	19220.0	6110.1
42	51.6	1.00	10489.1	5200.0	19220.0	5289.1
43	22.3	1.00	4533.1	5200.0	18553.1	0.0
44	48.1	1.00	9777.7	5200.0	19220.0	3910.8
45	48.7	1.00	9899.6	5200.0	19220.0	4699.6
46	12.4	1.00	2520.6	5200.0	16540.6	0.0
47	178.8	1.00	36346.1	5200.0	19220.0	28466.7
48	56.8	1.00	11546.2	5200.0	19220.0	6346.2
49	86.3	1.00	17542.9	5200.0	19220.0	12342.9
50	33.1	1.00	6728.5	5200.0	19220.0	1528.5
51	71.9	1.00	14615.7	5200.0	19220.0	9415.7
52	124.2	1.00	25247.1	5200.0	19220.0	20047.1
	2660.4			270400.		

MAXIMUM STORAGE = 19220.0

MINIMUM STORAGE = 6073.3

CATCHMENT AREA = 203.3 SQ. M.

COST FUNCTIONS

CATCHMENT $Y = 2.5000 + 0.0000 \cdot X + 0.000000 \cdot X^{**2}$ STORAGE $Y = 50.0000 + 0.0000 \cdot X + 0.000000 \cdot X^{**2}$

CATCHMENT EFFICIENCY FUNCTION

 $Y = 1.0000 + 0.0000 \cdot X + 0.000000 \cdot X^{**2} + 0.00000000 \cdot X^{**3}$

COSTS

CATCHMENT = \$ 508.19

STORAGE = \$ 961.00

TOTAL = \$1469.19

SUMMARY

The majority of water harvesting catchment and storage structures have usually been determined by precedent, irrespective of the amount of precipitation, actual water requirements, or relative unit costs of catchment and storage. For each structure there are many combinations of catchment and reservoir sizes that will provide an adequate water supply. The computations necessary for determining the relative sizes of catchment and storage for adequate water supplies at the lowest total cost are not difficult but are tedious

and time consuming when all variables are considered. A computer program was written to perform these computations and take into account all the variables. The program computes the costs of a series of catchment area-storage volume combinations that meet the water requirements and selects the combination with the lowest total cost. Two examples show the use of the program when various combinations of required conditions are considered.

APPENDIX I.-MAIN PROGRAM

THIS PROGRAM CALLED -OPTMZ- IS USED TO DETERMINE THE SIZES OF CATCHMENT AND STORAGE OF THE LOWEST COST, WHICH MEET NECESSARY WATER USAGE REQUIREMENTS FOR GIVEN PRECIPITATION, CATCHMENT EFFICIENCY, AND UNIT COST DATA.

THE METRIC SYSTEM IS USED FOR ALL VARIABLES.

THE PROGRAM HAS THREE SUBROUTINES

SUBROUTINE - CHECK - THIS SUBROUTINE DETERMINES BY INTERVAL IF SUFFICIENT WATER IS COLLECTED AND STORED TO SATISFY THE WATER REQUIREMENT FOR THAT INTERVAL PLUS THE SUCCEEDING INTERVAL.

SUBROUTINE - VARCST - THIS SUBROUTINE COMPUTES THE UNIT COSTS OF CATCHMENT AND STORAGE FROM THE COST FUNCTIONS.

SUBROUTINE - RESVR - THIS SUBROUTINE COMPUTES THE DIMENSIONS OF THE RESERVOIR WHEN USING OPEN TYPE STORAGE.

FOLLOWING IS A LIST OF THE REQUIRED INPUT DATA:

USEI - WATER USAGE REQUIREMENT BY INTERVAL.

PCPIN - PRECIPITATION DATA BY INTERVAL.

INTR - INTERVAL. THE NUMBER OF PAIRS OF MATCHED USE AND PRECIPITATION DATA; ENTER 12 FOR MONTHLY DATA.

ANGLE - ANGLE IN DEGREES OF RESERVOIR SIDES FOR OPEN TYPE STORAGE.

NOPEN - CODE FOR SELECTING OPEN OR CLOSED TYPE STORAGE:

ENTER 1 FOR OPEN TYPE STORAGE

ENTER 2 FOR CLOSED TYPE STORAGE

DCRMT - DESIRED DEPTH OF OPEN TYPE RESERVOIR IN METERS.

AOST - COEFFICIENTS OF UNIT COST FUNCTIONS OF CATCHMENT IN DOLLARS PER SQUARE METERS.

THIS IS A SECOND ORDER POLYNOMIAL FUNCTION.

SOST - COEFFICIENTS OF UNIT COST FUNCTIONS OF STORAGE IN DOLLARS PER THOUSAND LITERS.

THIS IS A SECOND ORDER POLYNOMIAL FUNCTION.

COEFF - COEFFICIENTS OF RUNOFF EFFICIENCY FUNCTION OF CATCHMENT.

THIS IS A THIRD ORDER POLYNOMIAL FUNCTION.

MINSTO - VALUE OF THE SMALLEST PERMISSIBLE SIZE OF STORAGE.

THIS MUST BE LARGER THAN THE LARGEST WATER USAGE REQUIREMENT FOR ANY INDIVIDUAL INTERVAL.

SRPC

COMMON TOTUSE, TOTPRC, USE (60), PRECIP (60), INTRVL

COMMON EFF (60), KSWT

COMMON ACOST (3), SCOST (3)

FILES; "AOST", "SOST", "USEI", AND "PCPIN" ARE DUMMY FILES FOR INPUT OF DATA FOR COEFFICIENTS OF AREA AND STORAGE COST FUNCTIONS, WATER REQUIREMENTS, AND PRECIPITATION DATA.

DIMENSION COEFF (4), AOST (3), SOST (3)

DIMENSION USEI (12), PCPIN (12)

DIMENSION COST(20), SAREA (20), SSRMAX (20)

INPUT DATA IS SUPPLIED BY THE FOLLOWING DATA STATEMENTS.

DATA USEI/

11355, 11355, 11355, 11355, 11355, 11355,

22710, 22710, 22710, 11355, 11355, 11355/

DATA PCPIN/

24.1, 22.4, 19.8, 8.6, 6.6, 10.9,

48.8, 62.7, 36.1, 24.6, 14., 26.2/

DATA INTR, ANGLE, NOPEN, DCRMT/

12, 45, 2, 2.1/

DATA AOST/

2.33, -.00115, 0./

APPENDIX I. - (cont'd) MAIN PROGRAM

```
DATA SOST/
  44,316, -.471, .0016/
DATA COEFF/
  .46, .0378, -.00117, .0000112/
DATA MINSTO/22710/
  INTRVL = INTR
  KSWT = 1
  ISWT = 1
  TOTPRC = .0
  TOTUSE = .0
```

TRANSFER OF COST, PRECIPITATION, AND USE DATA TO COMMON FILES.

```
DO 3 I = 1, 3
  ACOST (I) = AOST (I)
3 SCOST (I) = SOST (I)
  DO 4 I = 1, INTRVL
    PRFCIP (I) = PCPIN (I)
4 USE (I) = USEI (I)
```

COMPUTATION OF CATCHMENT RUNOFF EFFICIENCY BY INTERVALS.

```
DO 20 I = 1, INTRVL
  EFF (I) = COEFF (I)
DO 15 J = 2, 4
15 EFF (I) = EFF (I) + COEFF (J) * PRECIP (I) ** (J-1)
```

COMPUTATION OF TOTAL USE AND PRECIPITATION.

```
TOTPRC = TOTPRC + PRECIP (I)
20 TOTUSE = TOTUSE + USE (I)
```

SELECTION OF MINIMUM RUNOFF EFFICIENCY OF CATCHMENT.

```
EFMIN = EFF (1)
DO 22 K = 2, INTRVL
  IF (EFF (K) .LT. EFMIN) EFMIN = EFF (K)
22 CONTINUE
```

COMPUTATION OF FIRST APPROXIMATION OF REQUIRED CATCHMENT AREA.

```
AREA = TOTUSE/(TOTPRC * EFMIN)
AREA 1 = AREA
```

CALL SUBROUTINE CHECK: WATER STORAGE VOLUME ALLOWED TO INCREASE WITHOUT LIMITATION USING FIRST APPROXIMATION OF CATCHMENT AREA. IF WATER USE AND WATER COLLECTED DO NOT BALANCE, THE CATCHMENT AREA IS INCREASED BY 10 PERCENT INCREMENTS UNTIL A WATER BALANCE IS ACHIEVED.

```
25 CALL CHECK (ISWT, AREA, STRMAX, STRMIN, STOR, IBAL)
  IF (IBAL.EQ.1) GO TO 60
  AREA = AREA + AREA 1 * .1
  GO TO 25
60 ASTORI = AREA
  H1 = DCRMT
  IF (NOPEN.EQ.2) GO TO 70
  CALL RLSVR (ANGLE, STRMAX, ASTORE, H1, A, B)
```

COMPUTATION OF UNIT COSTS FOR CATCHMENT AND STORAGE; STORING OF COMPUTED STRUCTURE COST AND RESPECTIVE CATCHMENT AREA AND STORAGE VOLUME.

```

70  CALL VARCST (STRMAX, ASTORE, SCST, ACST)
    SAREA (I) = AREA
    SSRMAX (I) = STRMAX
    COST (I) = ASTORE * ACST + STRMAX * SCST

```

END OF FIRST STEP OF OPTIMIZATION PROCEDURE.

START OF SECOND STEP OF OPTIMIZATION PROCEDURE:

THE STORAGE VOLUME IS REDUCED IN INCREMENTS OF 5 PERCENT OF THE DIFFERENCE OF THE PREVIOUS COMPUTED STORAGE AND THE MINIMUM ALLOWABLE STORAGE. FOR THE 19 STORAGE INCREMENTS THE CATCHMENT AREA IS ALLOWED TO INCREASE BY 10 PERCENT INCREMENTS UNTIL A BALANCE BETWEEN WATER REQUIRED AND WATER COLLECTED IS ACHIEVED. THE COSTS AT EACH OF THE INCREMENTS ARE COMPUTED AND STORED ALONG WITH THE RESPECTIVE CATCHMENT AREAS AND STORAGE VOLUMES.

```

SSTORE = STRMAX - MINSTO
DO 114 I = 2, 20

```

COMPUTATION OF MAX. STORAGE VOLUME ASSIGNED SUBROUTINE -CHECK--

```

    STOR = STRMAX -.05 * SSTORE
    GO TO 112
110  AREA = AREA + 0.10 * AREA 1

```

CALLING SUBROUTINE -CHECK- WITH CODE FOR INDICATING A MAXIMUM STORAGE VOLUME HAS BEEN ASSIGNED.

```

112  ISWT = 2
    CALL CHECK (ISWT, AREA, STRMAX, STRMIN, STOR, IBAL)
    IF (IBAL .EQ.2) GO TO 110
    ASTORE = AREA
    IF (NOPEN. EQ.2) GO TO 113
    CALL RESVR (ANGLE, STOR, ASTORE, H1, A, B)
113  CALL VARCST (STOR, ASTORE, SCST, ACST)

```

COMPUTATION OF STRUCTURE COST: STORING OF COST AND RESPECTIVE CATCHMENT AREA AND STORAGE VOLUME.

```

    COST (I) = ASTORE * ACST + STOR * SCST
    SAREA (I) = AREA
114  SSRMAX (I) = STOR

```

END OF SECOND STEP OF OPTIMIZATION PROCEDURE.

START OF THIRD STEP OF OPTIMIZATION PROCEDURE:

SELECTION OF LOWEST VALUE OF PREVIOUSLY COMPUTED COSTS WITH THE RESPECTIVE CATCHMENT AREA AND STORAGE VOLUME.

```

    LCST1 = COST (I)
    ASTOR1 = SAREA (I)
    STMAX1 = SSRMAX (I)
    DO 115 I = 2, 20
    LCST2 = COST (I)
    ASTOR2 = SAREA (I)
    STMAX2 = SSRMAX (I)
    IF (LCST2. GT. LCST1) GO TO 115
    LCST1 = LCST2
    ASTOR1 = ASTOR2
    STMAX1 = STMAX2
115  CONTINUE

```

START OF FINAL COMPUTATION AND PRINTING OF RESULTS:

CALLING SUBROUTINE -CHECK- WITH CODE FOR INDICATING TABLE OF FINAL WATER
BALANCE IS TO BE PRINTED.

KSWT =2

CALL CHECK (ISWT, ASTOR1, STRMAX, STRMIN, STMAX1, IBAL)

IF (NOPEN, EQ.2) GO TO 116

FINAL COMPUTATION OF RESERVOIR DIMENSIONS AND UNIT COSTS.

CALL RESVR (ANGLE, STRMAX, ASTOR1, H1, A, B)

116 CALL VARCST (STRMAX, ASTOR1, SCST, ACST)

COMPUTATION OF CATCHMENT COST, STORAGE COST, AND TOTAL COST.

CST1 = ACST * ASTOR1

CST2 = SCST * STMAX1

COST1 = CST1 + CST2

PRINTING OF CATCHMENT AREA.

PRINT 170, ASTOR1

170 FORMAT (/5X, "CATCHMENT AREA =", F7.1, 1X, "SQ.M.")

PRINTING OF RESERVOIR DIMENSIONS FOR OPEN TYPE STORAGE.

IF (NOPEN, EQ.2) GO TO 172

PRINT 171, B, A, H1

171 FORMAT (5X, "STORAGE DIMENSIONS IN METERS", /7X, "WIDTH =", F7.1, /7X, "LENGTH =",
F6.1/7X, "DEPTH = ", F7.1)

PRINTING OF THE COST FUNCTIONS USED FOR CATCHMENT AREA AND STORAGE VOLUMES.

"Y" EQUALS THE UNIT COST AND "X" EQUALS THE AREA AND VOLUME RESPECTIVELY. AREA
IS IN SQUARE METERS AND VOLUME IS IN THOUSANDS OF LITERS.

172 PRINT 175, ACOST, SCOST

175 FORMAT (5X, "COST FUNCTIONS", /7X, "CATCHMENT", 2X, "Y =", F8.4, 1X, "+", F8.4, 2H * X, 1X, "+",
F8.6, 5H * X ** 2, /7X, "STORAGE", 4X, "Y =", F8.4, 1X, "+", F8.4, 2H * X, 1X, "+", F8.6, 5H * X ** 2)

PRINTING OF CATCHMENT EFFICIENCY FUNCTION. "Y" EQUALS THE EFFICIENCY AND "X"
EQUALS THE RAINFALL IN MM.

PRINT 176, COEFF

176 FORMAT (5X, "CATCHMENT EFFICIENCY FUNCTION", /7X, "Y =", F8.4, 1X, "+", F8.4, 2H * X, 1X, "+",
F8.6, 5H * X ** 2, 1X, "+", F10.8, 5H * X ** 3)

PRINTING OF COSTS

PRINT 177, CST1, CST2, COST1

177 FORMAT (5X, "COSTS", /7X, "CATCHMENT = \$", F7.2, /7X, "STORAGE", 2X, 2H = \$, F7.2, /7X, "TOTAL",
4X, 2H = \$, F7.2)

999 STOP

END

END OF MAIN PROGRAM.

APPENDIX I. - (cont'd) SUBROUTINE CHECK

SUBROUTINE CHECK (ISWT, AREA, STRMAX, STRMIN, LIMIT, IBAL)

DIMENSION MONTH (12)

REAL LIMIT

DATA MONTH/'JAN', 'FEB', 'MAR', 'APR', 'MAY', 'JNE', 'JLY', 'AUG', 'SPT', 'OCT', 'NOV', 'DEC'/

IF (KSWT.EQ.1) GO TO 11

PRINTING OF TABLE HEADINGS IN FINAL TABULATION.

PRINT 10

10 FORMAT (/2X, "MONTH", 2X, "PRECIP", 2X "EFFIC", 5X, "RUNOFF", 8X, "USE", 3X, "STORAGE", 4X,
"OVERFLOW", /2X, "OR WK", /10X, "(MM)", 11X, "(LITERS)", 4X, "(LITERS)", 2X, "(LITERS)", 3X, "(LITERS)"/)

11 STRMAX = .0

ACSTR1 = .0

COMPUTATION OF COLLECTED WATER, NET CHANGE IN WATER STORAGE AND AMOUNT OF
WATER IN STORAGE.

DO 50 I = 1, INTRVL

RUNOFF = AREA * EFF (I) * PRECIP (I)

CHANGE = RUNOFF - USE (I)

ACSTR2 = CHANGE + ACSTR1

CONDITIONAL CONTROL FOR DETERMINING IF MAXIMUM STORAGE IS ALLOWED TO CHANGE.

IF (ISWT, EQ. 1) GO TO 12

OVER = ACSTR2 - LIMIT

IF (OVER.GE.O.) GO TO 13

12 OVER = .0

GO TO 14

13 ACSTR2 = LIMIT

COMPUTATION FOR DETERMINING IF SUFFICIENT WATER IS AVAILABLE FOR NEXT SUCCEEDING
INTERVAL.

14 IF (STRMAX. LT. ACSTR2) STRMAX = ACSTR2

IF (I. LT. INTRVL) GO TO 15

KK = I - (INTRVL - 1)

IF (ACSTR2. GT. USE (KK)) GO TO 16

GO TO 100

15 IF (ACSTR2. GT. USE (I+1)) GO TO 16

GO TO 100

16 IF (I. LE. 1) GO TO 25

IF (STRMIN. LE. ACSTR2) GO TO 35

25 STRMIN = ACSTR2

PRINTING OF TABLE IN FINAL TABULATION.

35 IF (KSWT. EQ. 1) GO TO 47

IF (INTRVL. GT. 12) GO TO 45

PRINT 36, MONTH (I), PRECIP (I), EFF (I), RUNOFF, USE (I), ACSTR2, OVER

36 FORMAT (3XA3, 3XF6.1, 2XF4.2, 4XF8.1, 4XF7.1, 2XF8.1, 4XF8.1)

GO TO 47

45 PRINT 46, I, PRECIP (I), EFF (I), RUNOFF, USE (I), ACSTR2, OVER

46 FORMAT (3XI3, 3XF6.1, 2XF4.2, 4XF8.1, 4XF7.1, 2XF8.1, 4XF8.1)

47 IF (ACSTR2. LT. O.O) GO TO 100

ACSTR1 = ACSTR2

50 CONTINUE

IBAL = 1

IF (KSWT. EQ.1) RETURN

APPENDIX I. - (cont'd) SUBROUTINE CHECK

PRINTING OF TOTAL PRECIPITATION AND TOTAL USE IN FINAL TABULATION.

PRINT 55, TOTPRC, TOTUSE
55 FORMAT (8X, F7.1, 18X, F10.0)

PRINTING OF MAXIMUM AND MINIMUM STORAGE.

PRINT 60, STRMAX, STRMIN
60 FORMAT (/5X, "MAXIMUM STORAGE =", F8.1/5X, "MINIMUM STORAGE =", F8.1)
RETURN
100 IBAL = 2
RETURN
END

END OF SUBROUTINE -CHECK-

APPENDIX I. - (cont'd) SUBROUTINE VARCST

```
SUBROUTINE VARCST (STR, AREA, SCST, ACST)
ACST = ACOST (1)
SCST = SCOST (1)
STR = STR/1000.
```

COMPUTATION OF UNIT COSTS FROM COST FUNCTIONS.

```
DO 15 I = 2, 3
ACST = ACST + ACOST (I) * AREA ** (I - 1)
15 SCST = SCST + SCOST (I) * STR ** (I - 1)
STR = STR * 1000.
SCST = SCST/1000.
RETURN
END
```

END OF SUBROUTINE -VARCST-

APPENDIX I. - (cont'd) SUBROUTINE RESVR

SUBROUTINE RESVR (ANGLE, SSTORE, ASTORE, H1, A, B)

ANGL = 2.*3.14*ANGLE/360.

CTN = COS (ANGL) /SIN (ANGL)

V1 = SSTORE/1000

EQUATIONS FOR RESERVOIR DIMENSIONS ARE BASED ON THE SHAPE OF AN INVERT OBELISK
WITH GIVEN DEPTH AND SIDESLOPE. THE TOP WIDTH IS ONE-HALF THE TOP LENGTH

X = H1/2

Y = -1.5 * (H1 ** 2.) * CTN

Z = 1.33 * (H1 ** 2.) * (CTN ** 2.) - V1

A = (- Y + (ABS (Y) ** 2. - 4. * X * Z) ** .5) / (2. * X)

B = A/2

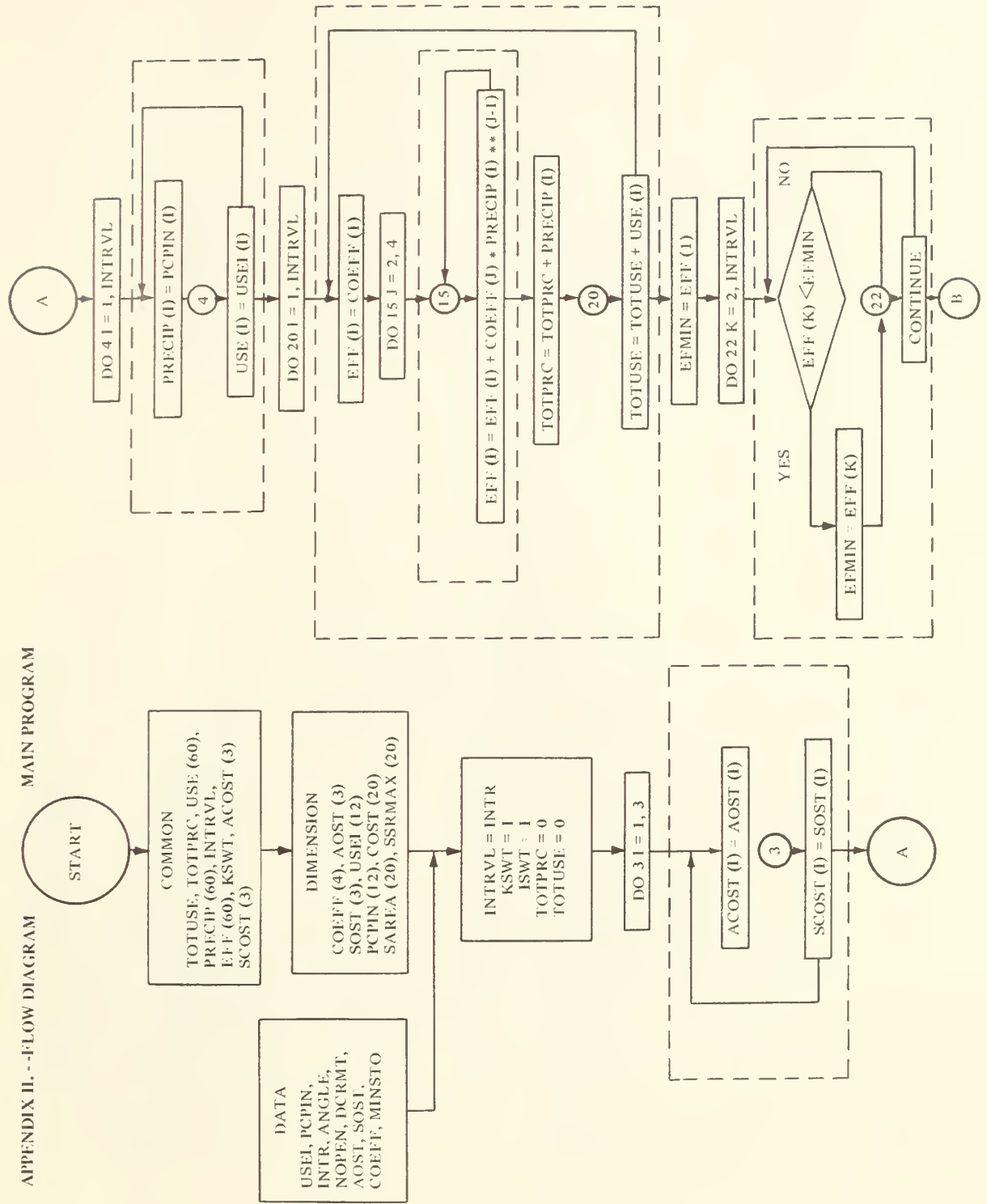
SURFA = A * B

ASTORE = ASTORE - SURFA

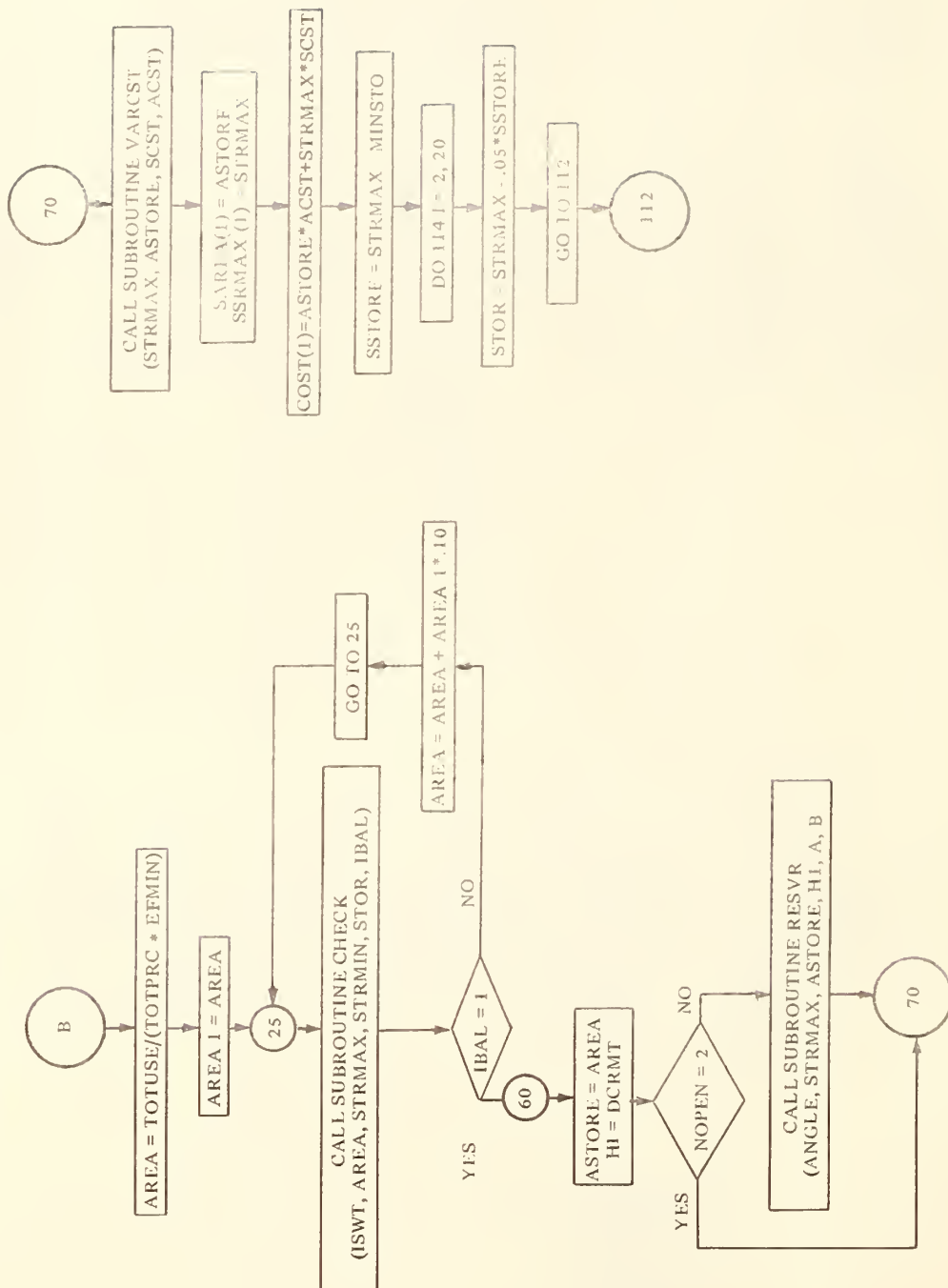
RETURN

END

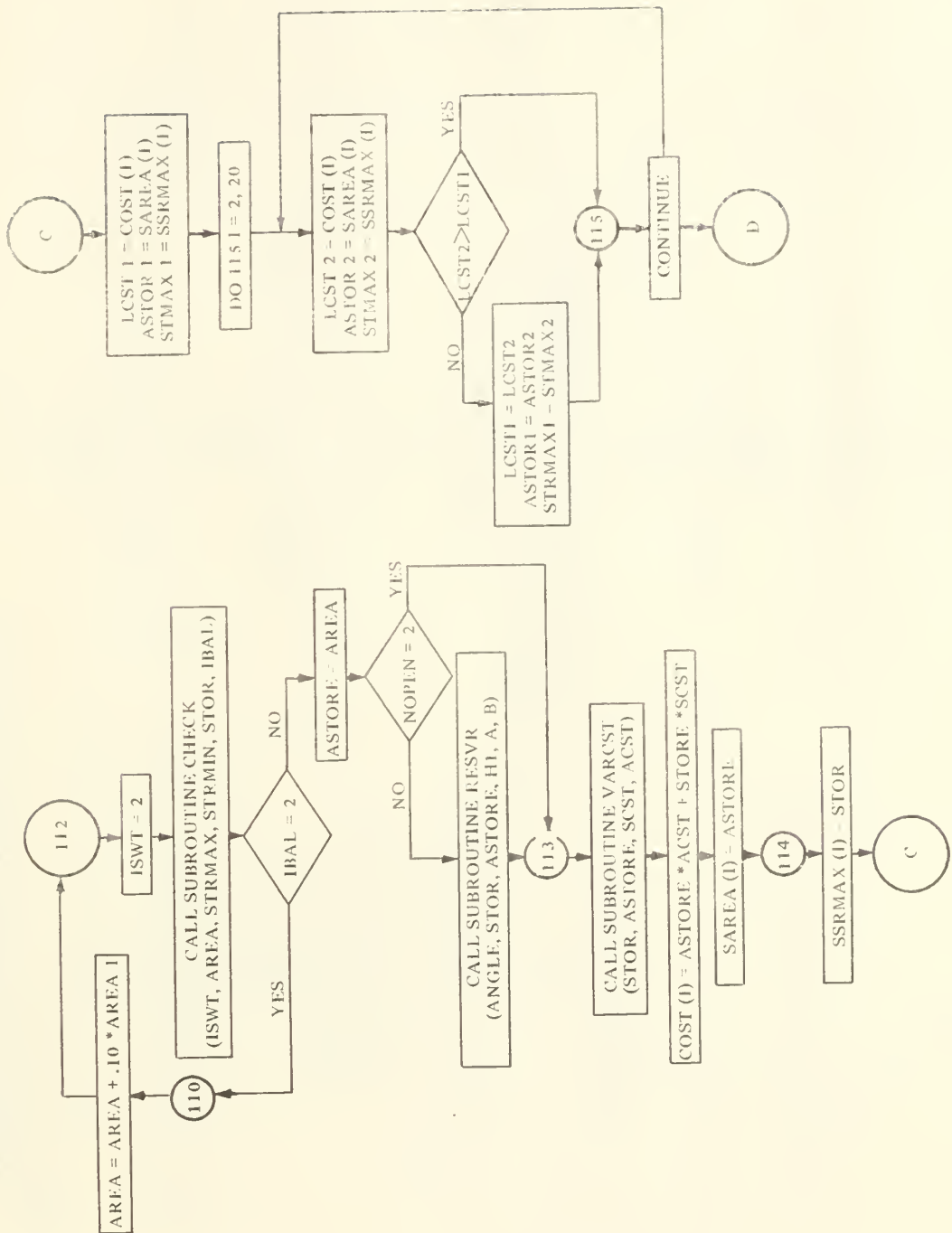
END OF SUBROUTINE -RESVR-



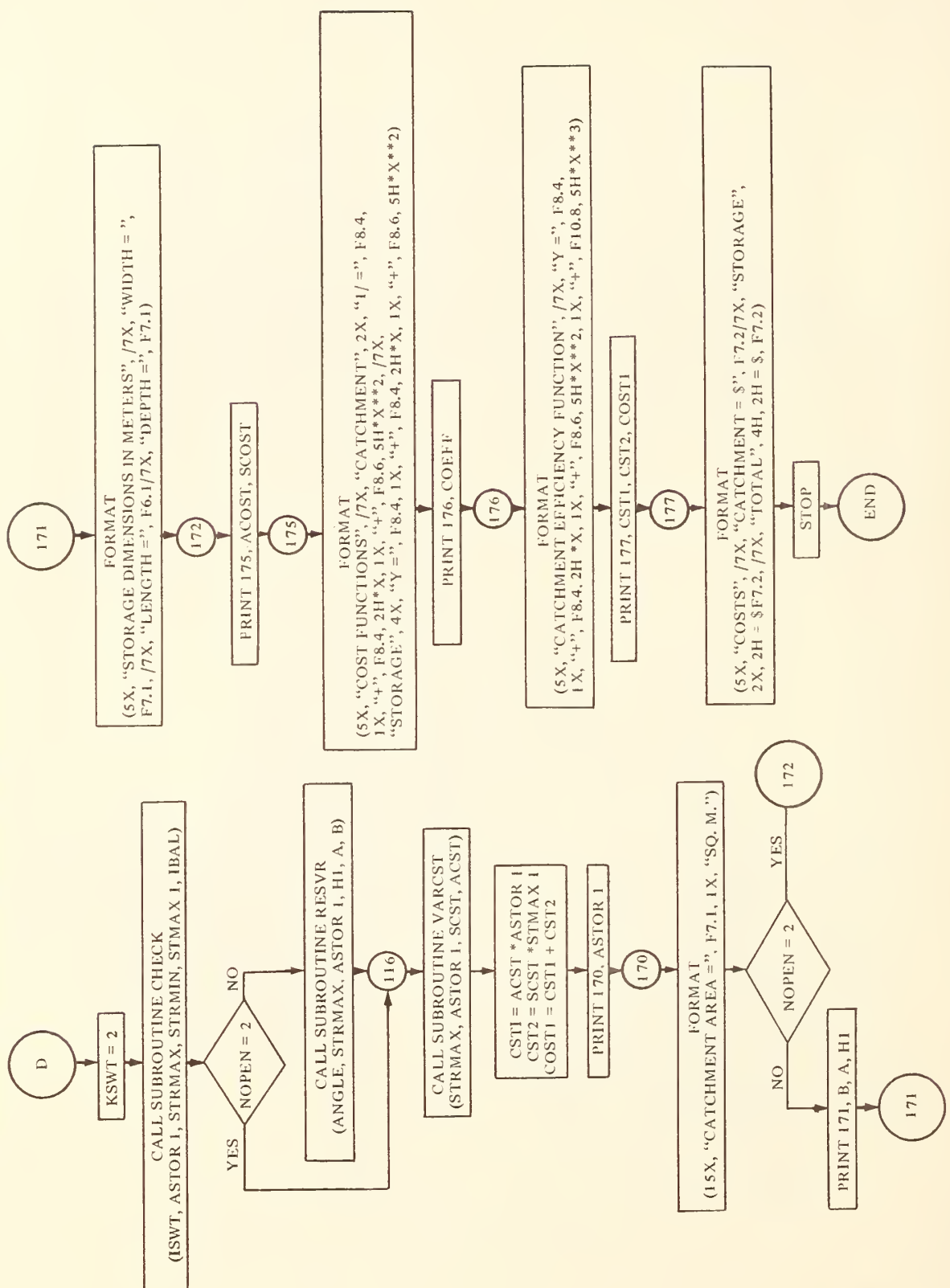
APPENDIX II. - (cont'd) FLOW DIAGRAM - MAIN PROGRAM



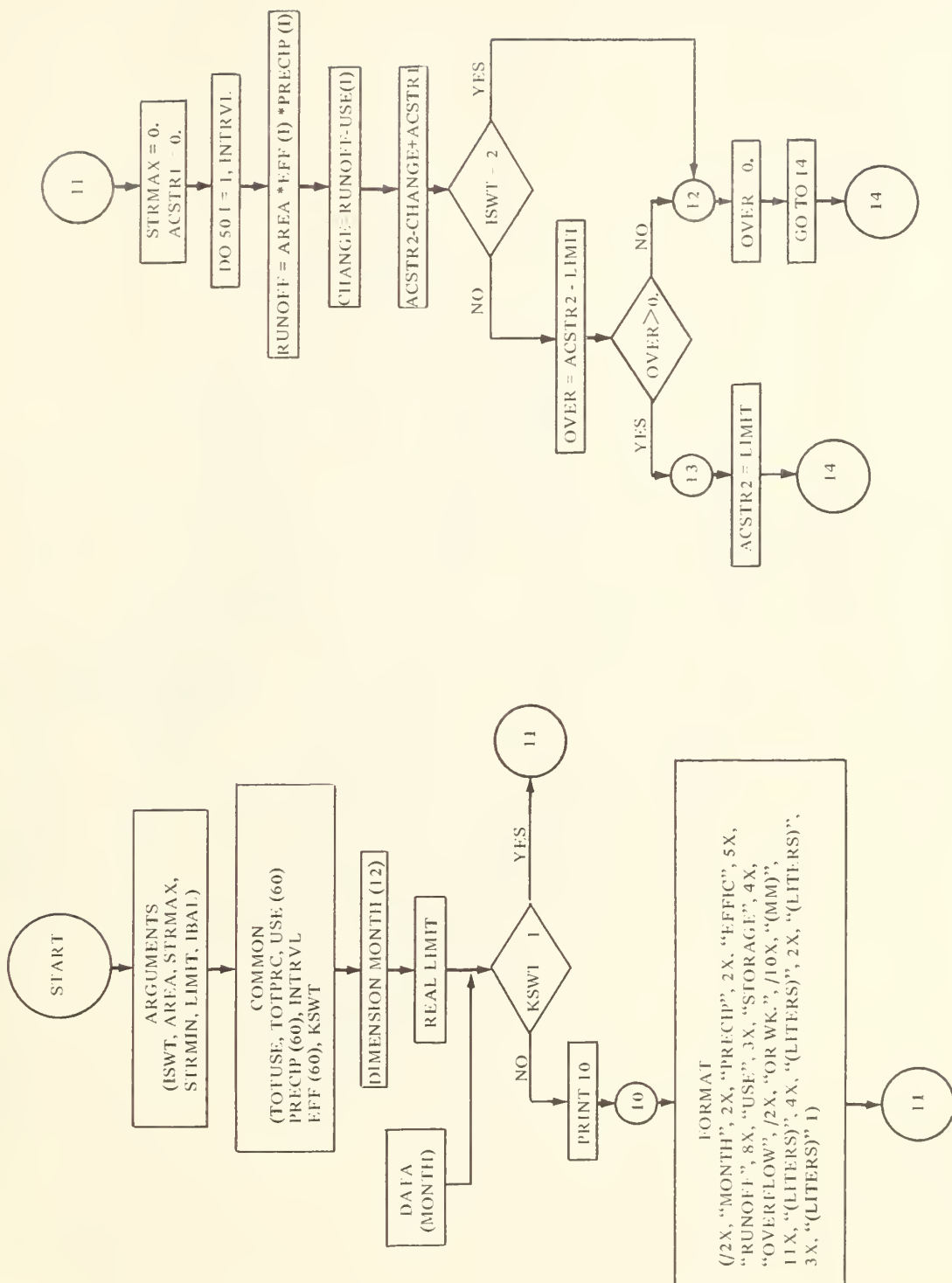
APPENDIX II. - (cont'd) FLOW DIAGRAM - MAIN PROGRAM



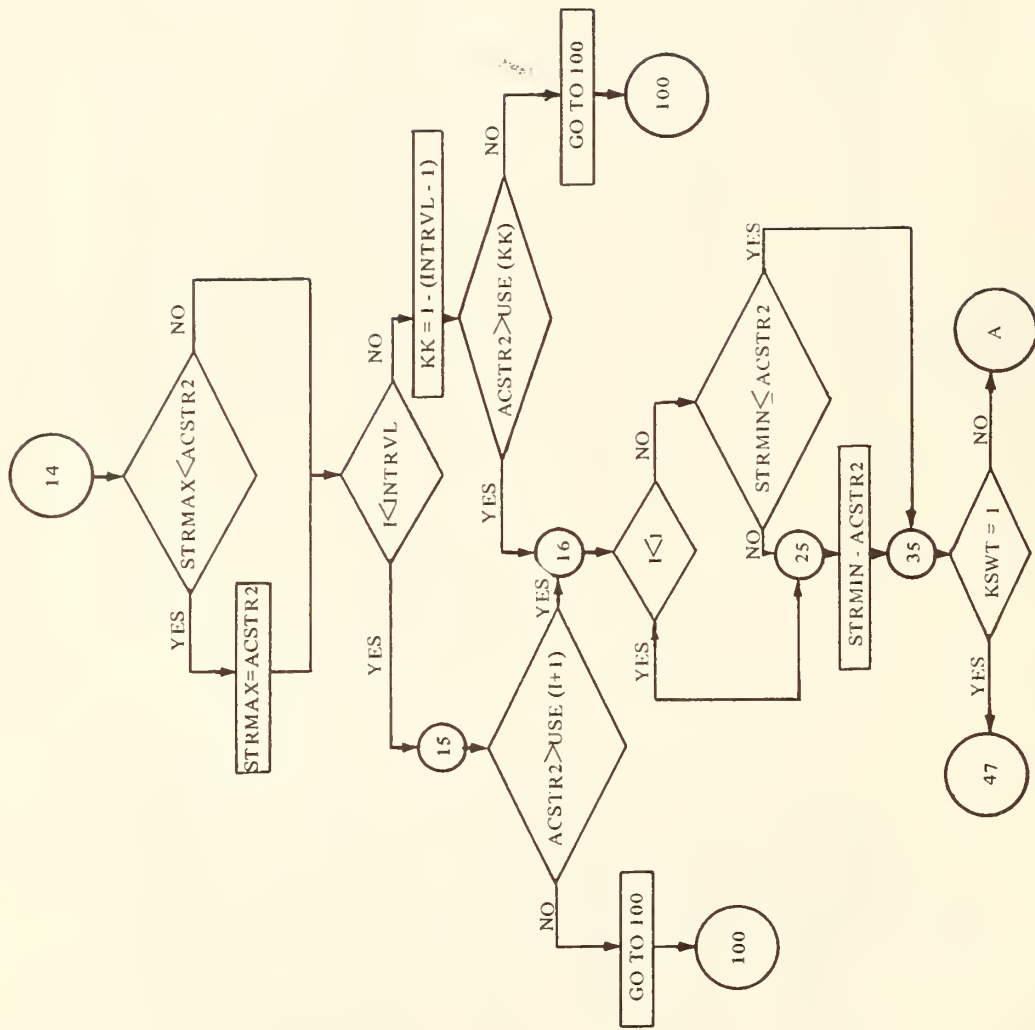
APPENDIX II. - (cont'd) FLOW DIAGRAM - MAIN PROGRAM



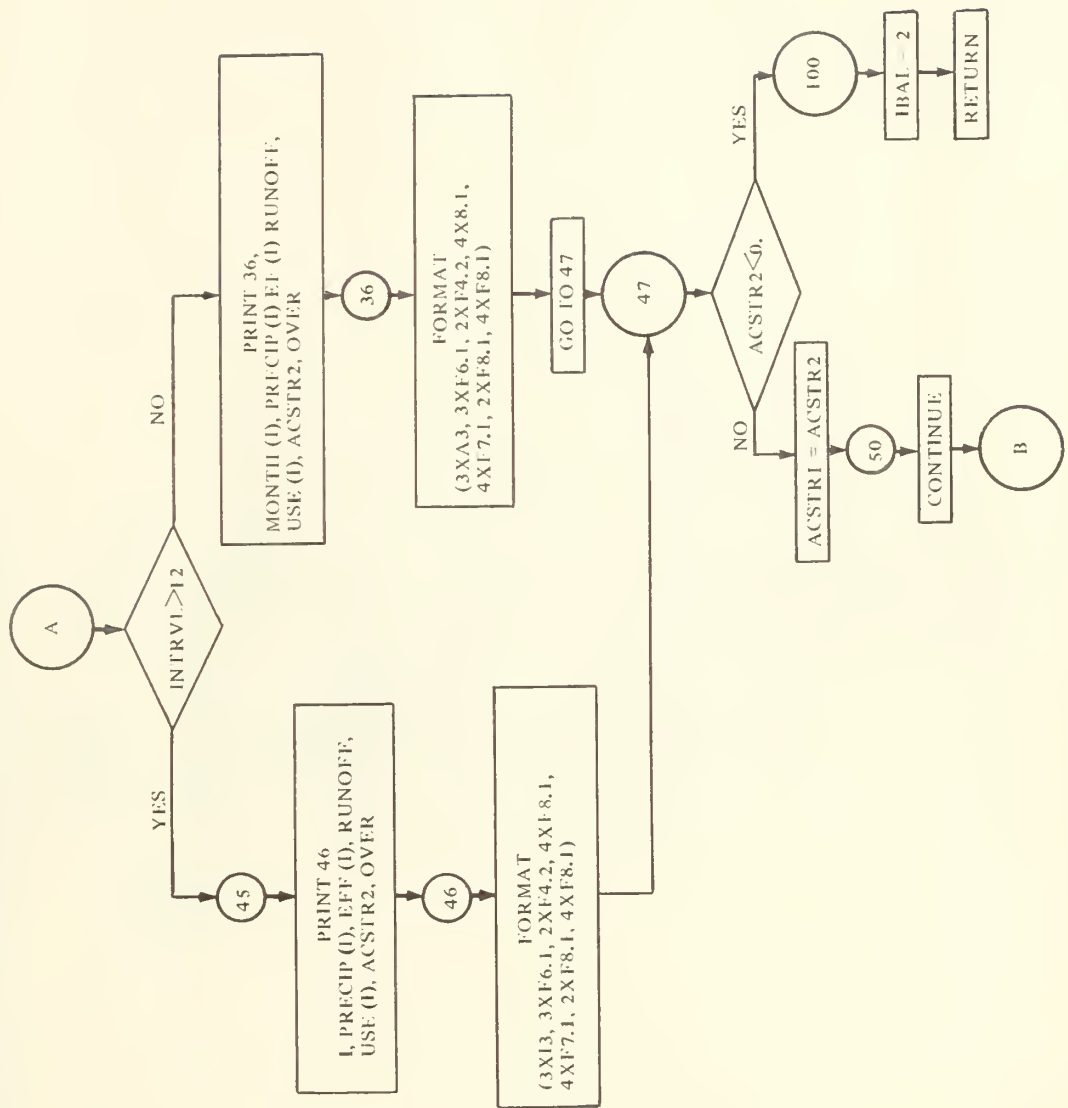
APPENDIX II. - (cont'd) FLOW DIAGRAM - SUBROUTINE CHECK



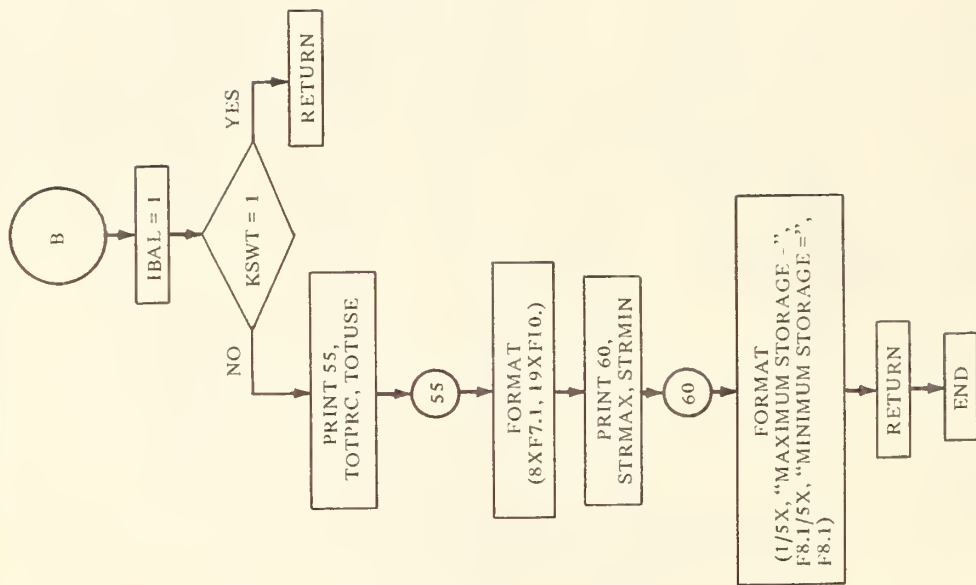
APPENDIX II. - (cont'd) FLOW DIAGRAM - SUBROUTINE CHECK



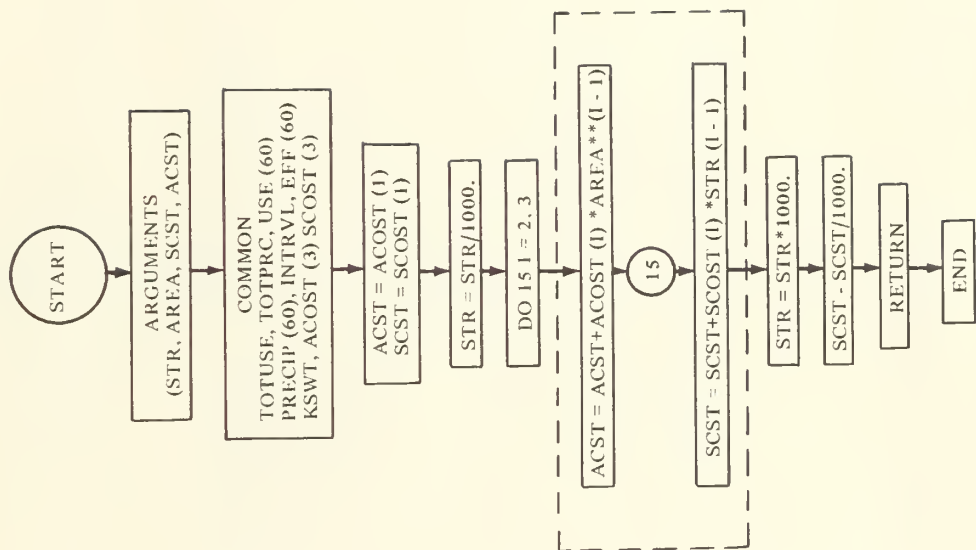
APPENDIX II. - (cont'd) FLOW DIAGRAM - SUBROUTINE CHECK



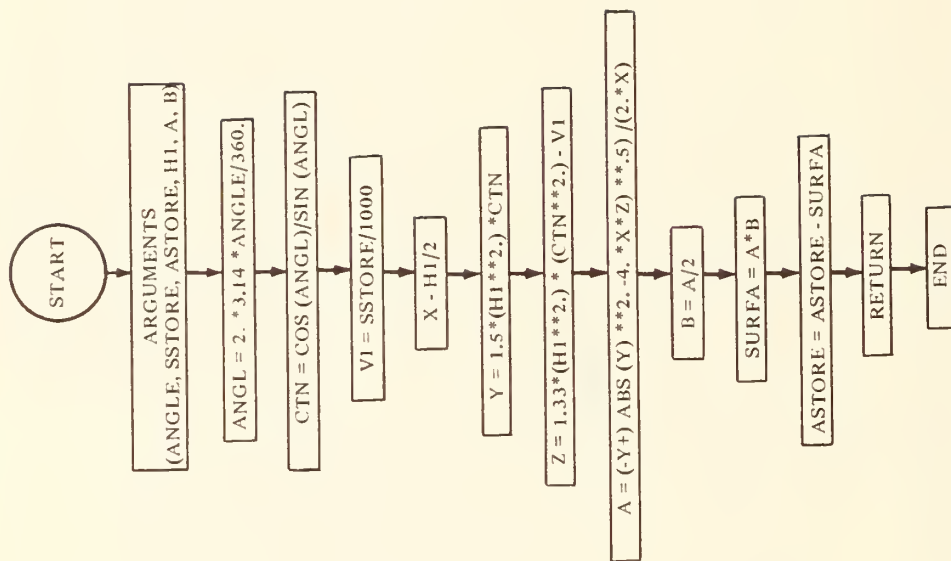
APPENDIX II. --(cont'd) FLOW DIAGRAM - SUBROUTINE CHECK



APPENDIX II. - (cont'd) FLOW DIAGRAM - SUBROUTINE VARCST



APPENDIX II. --(cont'd) FLOW DIAGRAM - SUBROUTINE RESVR



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